Baroclinic Data Assimilation in Korea/Tsushima Strait

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LONG-TERM GOALS

The long-term goal of the project is to develop, implement and verify an efficient 4D variational data assimilation algorithm into baroclinic primitive equation model. The algorithm is to be applied for the dynamically and observationally consistent reconstruction of the circulation in Korea/Tsushima Strait based on the synthesis of various types of observations in the region. The core of these observations comprises the data collected during the "Dynamical Linkages of Asian Marginal Seas" (LINKS) program. The project will enhance physical understanding of the circulation in the Korea/Tsushima Strait, a very important part of the East Asian Marginal Seas region. We expect that the proposed data assimilation approach will find wide applications in the analysis of the dynamics of various straits and passages in the World Ocean.

OBJECTIVES

Dynamical modeling of seasonally varying baroclinic circulation in the Korea/Tsushima Strait based on assimilation of the LINKS data pursues the following scientific objectives:

- To quantify the seasonally varying circulation in the Korea/Tsushima Strait and to determine seasonal variability of the thermohaline structure in the Strait using the data assimilation algorithm.
- To investigate the leading dynamical factors determining the structure of the circulation and the major sources of the uncertainties of our estimate of the circulation.
- To quantify the branching of the flow in the Korea/Tsushima Strait, it's seasonal variability and transports.
- To study the elementary dynamical process controlling seasonal variability of the Tsushima Warm Current and their influence on the branching of the through-flow in Tsushima Strait.
- To provide the dynamically and observationally consistent boundary conditions for Japan/East Sea modeling.

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- To formulate some recommendations on the design of the potential monitoring system in the Korea/Tsushima Strait.

APPROACH

Two lines of bottom-mounted ADCPs and Wave/Tide Gauges deployed during the LINKS project to monitor the inflow and outflow in the Strait provide an unparalleled opportunity for quantitative analysis of the circulation in the Strait and its variability on seasonal time scales. Combined with available CTD sections, XBT measurements, remote sensing and historical data, this yearlong dataset ensure adequate observational constraints for a baroclinic model of Korea/Tsushima Strait. To recover from the data a fuller representation of circulation in the Strait, we develop a variational data assimilation technique, which is able to treat different types of data in a statistically consistent way. Different correlation scales as well as temporal and spatial resolution of the assimilated data sets can be taken into account by accurate definition of the data error covariances underlying the statistical settings of the assimilation algorithm.

The implementation baroclinic variational data assimilation scheme for yearlong data sets requires a lot of computer resources. The choice of the model for the data assimilation is conditioned by an attempt to find a trade-off between complexity of a relevant dynamical model and feasibility of the implementation of a robust assimilation scheme. For data assimilation, we use a non-eddy resolving primitive equation model with simple but adequate dynamics representing the circulation on the sub tidal time scales and on spatial scales exceeding the Rossby radius. The validation of the proposed model will be thoroughly analyzed. The data assimilation approach is similar to that successfully applied in the Weddell, Bellingshausen, and Ross Seas (e.g., Grotov et al., 1998).

WORK COMPLETED

The work reported here covers the preliminary stage of the development and validation of the data assimilation algorithm. The objective of this stage was to analyze the data available for assimilation, to assess the consistency of different types of data with the model, and to prepare the model forward run (first guess solution), which can be used as a starting point for optimization procedure in data assimilation. The work included:

(1) The analysis of the available observations and initial preprocessing of the data.

The NRL Co-PIs performed the analysis of LINKS data (Perkins et al., submitted in 2000) and the preparation of the data for assimilation (interpolation, filtering and error covariance estimate). At the preliminary stage we used mainly the climatological data to constrain the model. LINKS velocity observations (Perkins et al., submitted in 2000) were used only to attract the model toward the observed transports in the Strait and to test the model results. The climatological data:

(i) monthly mean T and S climatologies prepared at RIAM on the base of the data of Japan Oceanographic Data Center and Russian surveys in the region (Far-Eastern Regional Hydromet. Inst., Vladivostok),

(ii) RIAM monthly mean wind stresses,

(iii) TOPEX/POSEIDON monthly mean altimetry, has been interpolated onto the model grid. Model bottom topography has been taken from ETOPO-5 data set without any smoothing. We

prepared two sets of the climatological data with resolution 5’ and 2.5’. Preliminary experiments were conducted on low-resolution grid.

(2) The modification of the model.

The model (Grotov et al., 1998) was upgraded to primitive equation, Boussinesq, hydrostatic, rigid lid approximation model. The rigid lid approximation is not crucial – the model can be switched easily to free surface mode at the expense of some increase of the number of control parameters. The differential equations of the model are discretized with the use of finite volume technique, thus permitting multiply connected regions with complicated coastal geometry and a realistic representation of bottom topography. The model treats explicitly Coriolis acceleration, bottom friction, vertical momentum diffusion, and pressure gradient terms. Explicit scheme allows to compute efficiently (approximately 10 ILU preconditioned GMRES iterations) a steady state diagnostic circulation for prescribed density field, wind stresses and sea surface elevation on open boundary. The implicit treatment of the baroclinic pressure gradient term requires the joint iterative solution of the momentum and density evolution equations (the latter is derived with use of the linearized equation of sea water state). The iterations are performed with BiCG algorithm, which utilizes the adjoint code of the model. The numerical scheme for solving the heat and salt evolution equations is implicit with respect to the vertical coordinate. Density is computed from T and S with the use of full nonlinear equation of state. For moderately non-linear solutions the model proved to be approximately 20 times more efficient then POM model. The time step of the model is limited mainly by CFL condition for horizontal advection.

The model is controlled by initial fields of T and S, open boundary distribution of T and S, sea surface height distribution on the open boundaries and surface fluxes. The initial velocity field is diagnosed from a steady state model equations, normal flow at the open boundaries assumed to be in geostrophic balance.

(3) *The model set up for the Korea/Tsushima Strait region.*

The model set up includes the grid generation, tuning of the model parameters and preparation of the first guess run of the model. The domain of model is shown on Fig.1. On the north, the region is bounded by the shelf break in the southern Japan/East Sea. The southern boundary of the region passes through the latitude of the Cheju Island. The region has three open boundary ports. The port between the Cheju Island and Korea coast give us the opportunity to trace the evolution of water masses entering the region from the northern part of the East China Sea. The closed boundary of the domain is delineated along the 20m isobath.

The success of data assimilation into non-linear model depends on the careful preparation of the first guess solution. To prepare such a first guess and to validate the model against the available data we performed a number of diagnostic calculations with the model (see Fig.1). Also we carried out the experiments with the prescribed boundary and initial conditions taken from monthly climatological data. The results of these experiments allow us to quantify how well the model is able to reproduce the seasonal cycle of climatological data and provide us with the estimate of the model error. The comparison of the through-flow structure and transports obtained in the course of LINKS program with the model results demonstrates the ability of the model to reproduce the data.

RESULTS

The experiments with the model driven by climatological data revealed strong inconsistency between TOPEX/POSEIDON and RIAM T/S monthly mean data, which leads to the formation of the intense boundary layers on the inflow open boundaries and unrealistic circulation in the Strait. The most probable reason for this inconsistency is the difference in correlation scales for these two data sets. To overcome this problem, the open boundary conditions were adjusted on each model time step by the minimization of the cost function. The cost function (1) penalizes deviations of the open boundary conditions from climatological data, (2) attracts the transport in the Strait to the LINKS transport estimate, and (3) enforces smoothness of the model fields in the vicinity of the open boundary in the cross boundary direction. The resulting circulation patterns do not exhibit any boundary layer behavior near open boundaries even in the case of the steady state diagnostic calculations (Fig.1).

The experiments with variational adjustment of open boundary conditions showed high controllability of the circulation in the Strait by the open boundary conditions specifying the structure of the inflow. By varying the inflow sea surface height data we were able to reproduce all major regimes of the through-flow splitting in the Strait observed in the Strait (Perkins et al., submitted in 2000).

IMPACT/APPLICATIONS

The proposed research will support the Japan/East Sea DRI through provision of a complete coverage of low-frequency flow and water mass structure in the Strait. The proposed analysis will benefit ONR modeling for this region through provision of a key boundary condition for everyone working in the Japan/East Sea.

TRANSITIONS

The model with the block of the variational open boundary conditions adjustment and data assimilation algorithm is being applied for the study of the baroclinic circulation on the Nova Scotia shelf (Gleb Panteleev, Memorial University, St. John's, Newfoundland, Canada)

RELATED PROJECTS

The project supports the ongoing field program in the area (especially the third phase of the LINKS Project) and the numerical modeling efforts at NRL (Stennis Space Center). We benefit from the collaboration with the individuals working on "Yellow and East China Seas response to winds and Currents" and LINKS programs.

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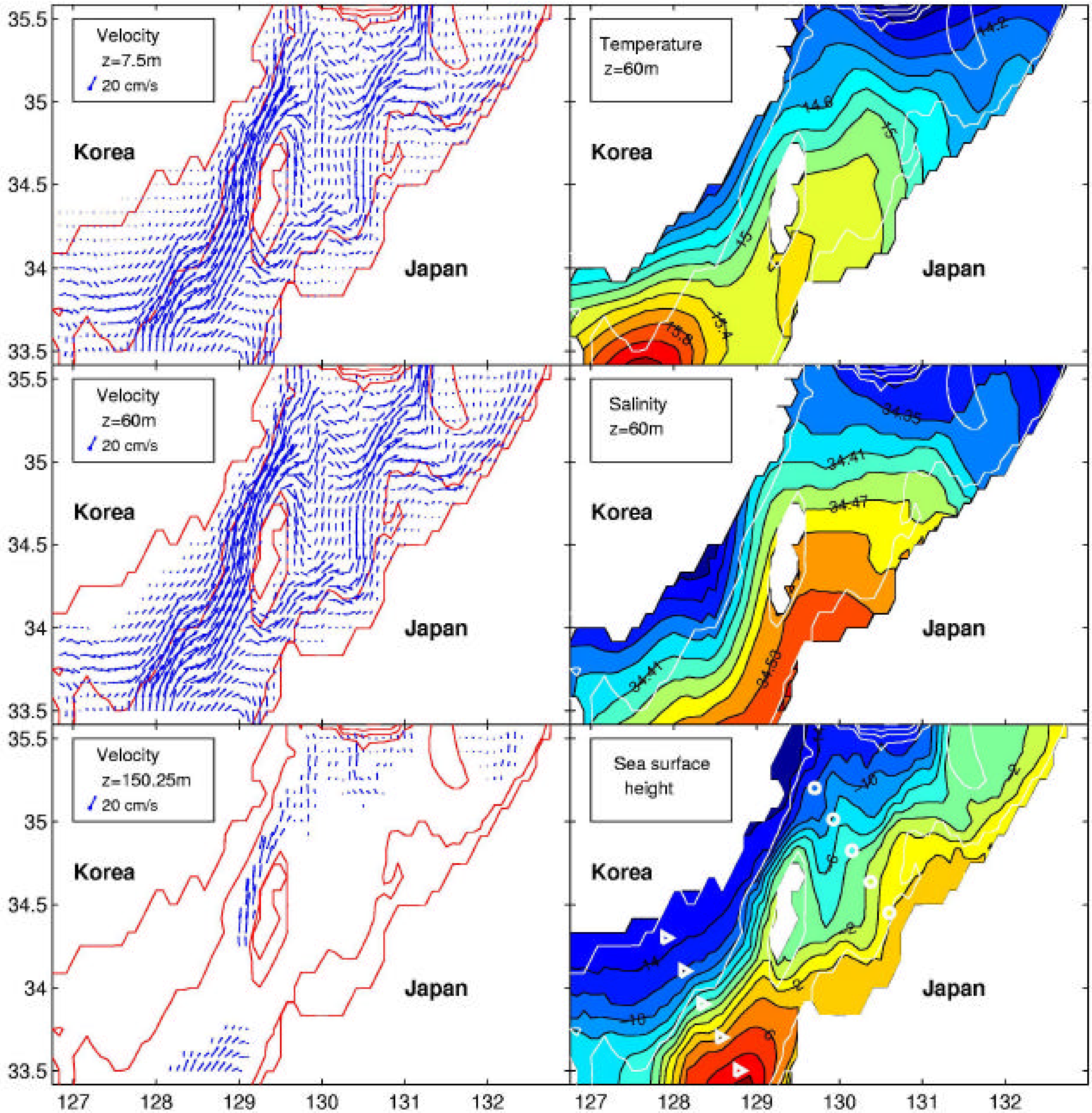

1. The results of the diagnostic model calculations with open boundary conditions adjustment for January climatologies. Red contours on the right panels and white contours on the left panels show the bottom topography. White triangles and circles on the "sea surface height" panel indicate the locations of LINKS observations.